

# A Study of Future Communications Concepts and Technologies for the National Airspace System—Part II

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**Abstract—** The National Aeronautics and Space Administration (NASA) Glenn Research Center (GRC) is investigating current and anticipated wireless communications concepts and technologies that the National Airspace System (NAS) may need in the next 50 years. NASA has awarded three NASA Research Announcements (NAR) studies with the objective to determine the most promising candidate technologies for air-to-air and air-to-ground data exchange and analyze their suitability in a post-NextGen NAS environment. This paper will present progress made in the studies and describe the communications challenges and opportunities that have been identified during the studies' first year.

## TABLE OF CONTENTS

1. INTRODUCTION.....	1
2. HONEYWELL.....	2
3. ROCKWELL COLLINS.....	5
4. XCELAR.....	9
5. CONCLUSIONS.....	10
6. ACKNOWLEDGEMENT.....	11
7. REFERENCES.....	11

## 1. INTRODUCTION

NASA's NextGen Concepts and Technology Development (CTD) Project integrates solutions for a safe, efficient and high-capacity airspace system through joint research efforts and partnerships with other government agencies. The CTD Project is one of two within NASA's Airspace Systems Program and is managed by the NASA Ames Research Center. Research within the CTD Project is in support the 2011 NASA Strategic Plan Sub-Goal 4.1: Develop innovative solutions and advanced technologies, through a balanced research portfolio, to improve current and future air transportation. The focus of CTD is on developing capabilities in traffic flow management, dynamic airspace configuration, separation assurance, super

density operations, and airport surface operations. Important to its research is the development of human/automation information requirements and decision-making guidelines for human-human and human-machine airport decision-making. Airborne separation, oceanic in-trail climb/descent and interval management applications depend on location and intent information of surrounding aircraft. ADS-B has been proposed to provide the information exchange, but other candidates such as satellite-based receivers, broadband or airborne internet, and cellular communications are possible candidate's. For further information, the CTD project plan can be found at: [http://www.aeronautics.nasa.gov/pdf/ctd\\_project\\_plan\\_2011\\_508.pdf](http://www.aeronautics.nasa.gov/pdf/ctd_project_plan_2011_508.pdf)

In the Spring of 2012, NASA Ames Research Center issued an amendment (CTD1 Subtopic 3) entitled: "Technology Candidates for Air-to-Air and Air-to-Ground Data Exchange" calling for proposals to NASA Research Announcement (NRA) "Research Opportunities in Aeronautics", NNH11ZEA001N. Future applications such as airborne separation, oceanic in-trail climb/descent and interval management depend on the location and intent information of the surrounding aircraft with respect to an aircraft. Presently, Automatic Dependent Surveillance Broadcast (ADS-B) technology has been proposed to provide that information. However, satellite-based communications, broadband or airborne internet, and cellular communications have also been proposed as possible candidates. The purpose of this solicitation was to identify the air-to-air and air-to-ground communication methods for NextGen and beyond NextGen operations. The specific goals are as follows:

1. Identify existing or emerging technology candidates (and their integration), including but not limited to ADS-B, suitable for air-to-air and air-to-ground communications over a NAS modernization horizon of 50 years.
2. Quantify the functional attributes and characteristics of each candidate, including (but not limited to)

communications range, bandwidth, latency, integrity, reliability, and security.

3. Map the technology candidates to specific air traffic management applications where they will be most beneficial and cost effective.

4. Identify the infrastructure and architecture needs of the potential technologies for air-to-air and air-to-ground exchange.

5. Identify rough magnitude cost estimates, or relative cost comparisons, and any technological characteristics such as bandwidth, and reliability.

6. Provide assessment of how these technologies could be used for air traffic management applications including but not limited to airborne separation and interval management.

7. Identify vulnerabilities and security issues and mitigation of any proposed concepts.

The proposer was asked to identify current and future technologies that would be useful for air-to air and air-to-ground information exchange related to air traffic management applications. This was an exploratory NRA subtopic and there was flexibility for the proposer to select an appropriate approach. The anticipated duration was 24 months from the date of the award. The expected outcomes, deliverables, and, schedule were defined as follows:

1. A report describing technology candidates (and their integration) that will allow air-to-air and air-to-ground data exchange. Describe strengths and weaknesses of each. The report should include but not be limited to how the ADS-B could be made more cost effective. (Q3)

2. A report documenting infrastructure and architectural needs of these identified technology candidates. (Q4)

3. A report describing comparison of multiple alternatives and/or their integration based on costs, bandwidth, safety, reliability and security to support air-to-air and air-to-ground communications appropriate for future air traffic management operations. (Q5)

4. A report describing alternative technologies, their integration, dependencies on infrastructure and their potential use for air traffic management applications including but not limited to airborne separation and interval management. (Q7)

5. A detailed description of most promising technology alternative(s). (Q8)

The proposals were due on April 3rd, 2012. NASA Glenn Research Center led the evaluation of submitted proposals. In September 2012, three contract awards were made. They were: A Study of NAS Data Exchange Environment through 2060 (Honeywell, Columbia, MD, Alope Roy/PI); NASA Com50 (Rockwell Collins, Cedar

Rapids, IA, Joel Wichgers/PI); and, Technology Candidates for Air-to-Air and Air-to-Ground Data Exchange (Agile Defense LLC, Hopkins, MN, Brian Hayes/PI). These three studies all began in October 2012 and have a 24 month duration. This paper provides a summary of approximately the first year of effort for each study. A paper summarizing the first six months effort can be found in reference [1].

## **2. HONEYWELL**

### **BACKGROUND**

Honeywell has been studying communication technologies suitable to support future Air Traffic Management needs in the 2060 time frame. The study was sponsored under NASA's Next Generation (NextGen) Concepts and Technology Development (CTD1) project, sub-topic area-3: Candidates for Air-to-Air and Air-to-Ground Data Exchange. This section summarizes Honeywell's initial findings to characterize candidate technologies for "Beyond NextGen" communications.

### **HONEYWELL TECHNICAL APPROACH**

The technical approach started with the characterization of existing, upcoming and embryonic communication technology candidates. These technologies were identified by literature survey of public domain information, including standards, specifications, research papers and reports published at various forums around the World. Through the course of the project, increasingly fine filters were applied through objective, criteria-based analyses and assessments. For example, a filter eliminated candidates that do not meet basic ATM needs and criteria. Those criteria were derived from ICAO Global Navigation Plan and Communications Operating Concepts and Requirements (COCR), which was jointly defined by Eurocontrol and the United States Federal Aviation Administration (FAA). Successive filters examined architectural impacts and costs to ascertain the best value alternatives from the initial set of technology candidates. This report summarizes the findings of Honeywell through the first year of performance period, which includes candidate technology characterization, and results from architectural and cost analyses.

### **COMMUNICATION ENVIRONMENT IN 2060**

NextGen represents a paradigm shift from rules-based to performance-based operations in the NAS, and data exchanges are a key enabler to achieve reduced aircraft separation and efficient movements in a more dense and dynamic airspace environment. As needs for situational awareness, airspace avoidance, and weather avoidance information increase with more complex and dynamic operations, advanced communication technologies coupled

with innovative and cost-effective applications of existing technologies will be necessary to meet the required performance objectives. Communication beyond NextGen is expected to be multi-faceted whereby airborne platforms maintain multiple communication channels simultaneously with other terrestrial and airborne platforms to meet the availability, integrity and continuity of service requirements for autonomous operations.

## CANDIDATE TECHNOLOGY ANALYSIS

### Current Technologies

Current communication technologies for aviation include dedicated HF, narrow-band VHF systems; shared low-speed satellite systems such as INMERSAT Classic and IRIDIUM; and IEEE 802.11 wireless systems operating on shared Industrial, Scientific and Medical radio spectrum. These legacy systems will not meet the stringent performance requirements of the ATM systems Beyond NextGen.

### Emerging Technologies

The US and Europe defined the Future Communications Infrastructure (FCI) for safety critical communications in the 2020 timeframe and beyond. The FCI identified AeroMACS (Aeronautical Mobile Airport Communications System) based on the IEEE 802.16 standard for airport terminal area, L-band systems for terrestrial enroute and next generation satellite systems for oceanic, remote and polar regions.

In addition to the above, some emerging commercial technologies targeting passenger communications are also under various stages of development. These technologies include 4G/5G cellular, Swift Broadband, IRIDIUM Next, Ka/Ku band SATCOM, and other commercial satellite based technologies. Some of these technologies, for example, 4G/5G cellular and Ka/Ku band SATCOM, will evolve with the commercial market and will continue to serve the future needs. Some others, such as L-band and VHF may remain in place to satisfy very specialized aviation environments and services.

### Embryonic Technologies

Free space optical (FSO) communication is the most notable embryonic technology to consider for the aviation environment. X-Ray is an extension of the FSO. However, X-Ray communications requires very high power and therefore mostly effective indoors over short ranges.

It is anticipated that the dominant challenges of FSO, which are atmospheric attenuation and signal acquisition and maintenance from high-speed, mobile platforms will be mostly mitigated over the next fifty years. Therefore, FSO will be a viable technology candidate for Beyond NextGen aviation while X-Ray may still be limited to indoor usage where high-power radiation may not be required.

## Evaluation Criteria

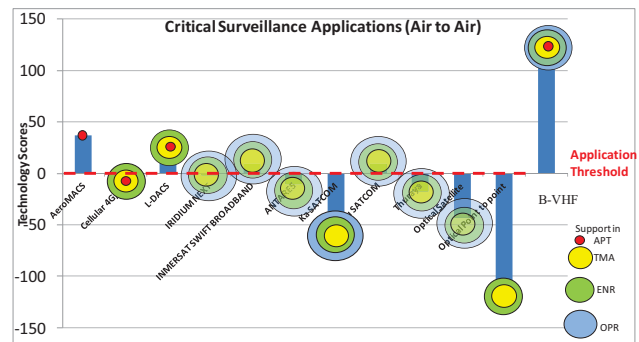
The communication performance requirements for the technology elements were derived from the Future Radio System (FRS) in the Communications Operating Concept and Requirements (COCR) document. Specifically, the COCR Phase 2 worst case loads in 2030 were used as the initial values and they were escalated at an annual rate of 2.5% over 30 years to derive the loads for year 2060 timeframe. Subsequently, those loads were used as basis for establishing the evaluation criteria for latency, continuity, integrity and availability.

### Technology Characterization

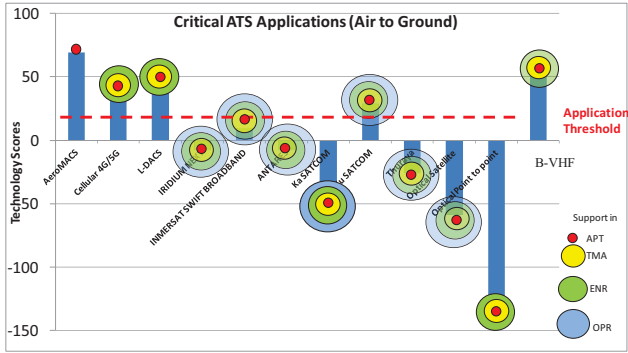
The technology candidates were assessed by comparing their performance against the needs of various aeronautical services. A weighted score was developed that normalized the performance of the technologies in various airspaces to meet the critical needs defined under the evaluation criteria. Then a final score for each technology was obtained by summing its weighted scores and then the technology candidates were ranked based on their final scores.

For the purpose of this analysis, some of the critical NextGen ATM applications involving Trajectory Based Operations, Separation Assurance procedures including Interval Management, In-Trial Procedures, Crossing and Passing, Continuous Descent Approach, FIS services and SWIM applications are considered and the results are extrapolated for the overall requirement.

Figure 1 and Figure 2 show the ranking of the technology candidates to meet the critical air-to-air and air-to-ground ATM applications respectively. From pure technology perspective, it can be observed that broadband VHF clearly outranks all other technologies to support air-to-air surveillance services. On the other hand, multiple technologies will be suitable for the air-to-ground environment and a hybrid technology solution may be desired to cover all the services in all applicable airspaces.



**Figure 1: Technology capability scores for Air-to-Air Networking**



**Figure 2: Technology capability scores for Air Ground Datalink**

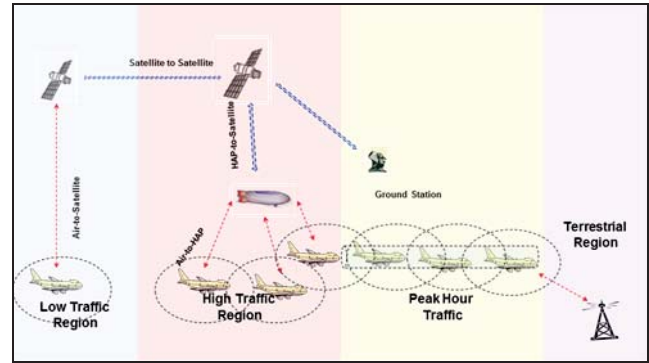
### ARCHITECTURE ANALYSIS

To further assess how well the candidate technologies will work and meet the communication requirements of future ATM applications, a comparative analysis of the architectures is conducted to rank the relative effectiveness of the architectures and to down-select technologies to the most promising candidates based on architectural considerations. The communications architecture for this study includes the aircraft and ground radio subsystems and supporting infrastructure components. Three representative architectures were created using the top ranked technologies:

- **Architecture Option 1** is based on the future cellular technology combined with High Altitude Platforms (HAP) to extend cellular service over oceanic, remote, and polar (ORP) regions. Free Space Optical (FSO) supplements this architecture for backend HAP-to-HAP or HAP-to-Ground communications.
- **Architecture Option 2** is based on the SATCOM operating mostly in the Ka band as these systems offer higher bandwidth with smaller antenna sizes than Ku band systems.
- **Architecture Option 3** is based on Broadband VHF technology, which offers support to air-to-air networking in all regions. This technology can be extended to support air/ground communication by using a terrestrial tower infrastructure similar to the ones installed for VHF networks. As this technology is based on the limited VHF spectrum, it will have limited throughput.

It was observed that each of those architecture alternatives by itself did not meet future ATM performance requirements in all airspaces. However, those limitations could be easily overcome by combining the architectures to create a diverse ATM communication system with complementary technology elements. This hybrid architecture is shown in Figure 3 below. The recommended architecture utilizes cellular technology over

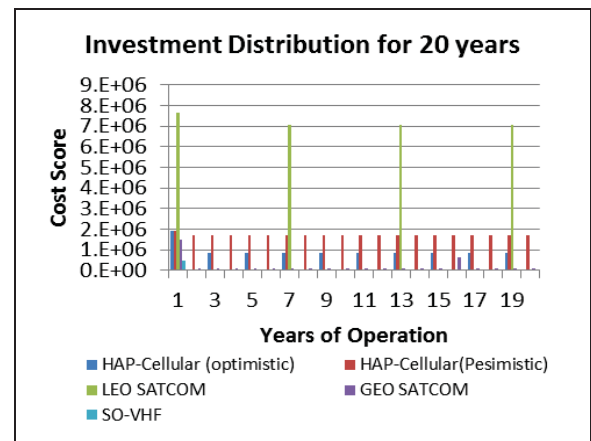
terrestrial airspace. For typical ORP regions satellite systems will suffice. However, in high-density ORP regions, it might be desirable to use cellular air/ground communications supplemented with HAPs interconnected by FSO links. For low-latency, tactical surveillance services, such as ADS-B, an air-to-air broadcast VHF network may be adequate.



**Figure 3: Recommended Hybrid Architecture**

### COST ANALYSIS

To further analyze the potential of the proposed architectures, overall system expenditure against benefits were compared to choose the right architecture for NAS environment with minimum cost outflows. Considering the dynamism involved in the communication industry, forecasting the actual costs of future systems that would be implemented after 50 to 60 years is very difficult. Therefore, a relative estimation methodology was adopted to compare the technologies over different system life cycle elements, which included technology development, implementation, deployment, system operations and maintenance. Cost sensitivity of the three proposed architectures was then analyzed against the data throughput benefit metric. Figure 4 shows the level of investments that might be required for various architectures over a 20-year operating life.

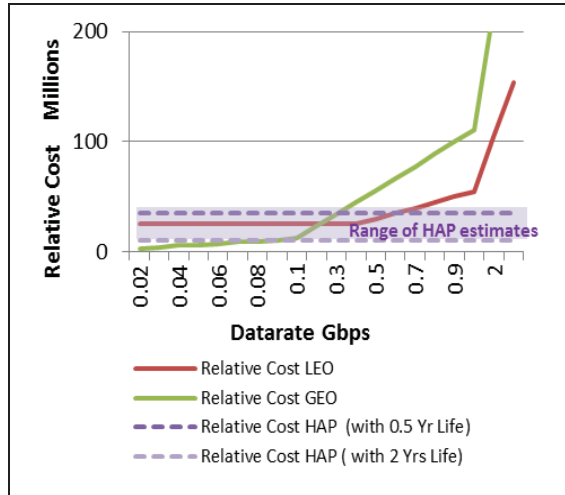


**Figure 4: Estimated Investment Timeline**



The estimates indicated that LEO Satellites will require maximum investment due to shorter lifespan of satellites that drive higher level of launch and satellite costs. Similarly, HAP-based architectures will require higher investments to refresh the HAPs every six to twenty-four months.

Ability of the chosen architecture to yield a sustained data throughput with a defined quality of service was selected as the benefit metric. Cost sensitivity of the three proposed architectures was then analyzed against the data throughput benefit metric. As shown in Figure 5, GEO SATCOM is most cost effective for lower system throughputs below 100 Mbps. Depending on the operating life of HAPs, LEO SATCOM may provide better cost model up to 700 Mbps. HAP-based systems with cellular and FSO technologies will provide the best cost efficiency for system throughput requirements approaching 1 Gbps and higher.



**Figure 5: Relative cost vs. Throughput**

## CONCLUSIONS & RECOMMENDATIONS

It was observed that broadband VHF technology offered the most economical solutions for tactical, air-to-air communications that required low data throughput and did not tolerate high latency jitter. This class of communication services includes ADS-B. It should be noted that the current aeronautical assignments of VHF spectrum was assumed to remain constant and was reallocated at no cost to develop this broadband VHF architecture. A similar approach is also feasible for deployment in the L-band if the spectrum allocated for navigation can be reassigned to aeronautical communications.

For air/ground communications, future cellular will be most cost effective for terrestrial regions because most of the life cycle cost elements can be shared with

consumer telecommunication industry. Geostationary satellite systems will offer better cost/benefit in ORP regions as the data throughput requirements are expected to remain low in those regions. With the increase in throughput demand, a HAP-based cellular architecture may evolve to be a better alternative.

The data exchange environment of future NAS will be very challenging due to the diversity of the airspace users and the reliance of future ATM services on deterministic, reliable data communications. Therefore, it was concluded that a single technology will not be adequate to support all of NAS data exchange needs beyond NextGen in 2060 timeframe. A hybrid architecture consisting of cellular, HAP, geostationary SATCOM, and broadband VHF/L-band technologies was recommended based on the maximum data throughput requirement of 1 Gbps per service volume.

The effectiveness of the HAP-based cellular and ad-hoc networking environment of the broadband VHF/L-band concept should be further studied by developing appropriate simulation models. The simulation models should permit sensitivity analysis against changing requirements such as mix of aircraft types, throughputs, flow management, latency, etc. As new technologies evolve over the next few decades, this entire exercise should be repeated to re-assess their impact on the ATM and the data exchange environment beyond NextGen.

## NEXT STEPS

In Phase-II of the NASA CTD1 contract, a simulation model will be developed to assess the performance of the proposed technology architecture against the projected performance requirements. The model may utilize existing NASA traffic flow tool/s to extrapolate NAS ATM environment to the year 2060 time frame.

## 3. ROCKWELL COLLINS

### BACKGROUND

Today's National Airspace System (NAS) has served the community well in meeting past operational and safety needs. It has made effective and prudent use of air-routes, procedures, and traditional Communication, Navigation, and Surveillance systems to provide a level of capacity that was sufficient for the demand while maintaining a strong safety record. However, without change, the NAS will be unable to realize the capacity, efficiency, safety, security, and environmental improvements that are being demanded for the Next Generation Air Transportation System (NextGen) and beyond. To realize these improvements, the long term NextGen and beyond infrastructure is envisioned to be built on better, more capable, and optimally integrated communications, navigation, surveillance, information management, and decision support systems.

Wireless communications including both Aircraft-to-Aircraft (A-A) and Aircraft-to-Ground (A-G) is an essential infrastructure element necessary to realize the future NAS vision such that the appropriate information is available at the required quality of service to enable the Air Traffic Management (ATM) systems to better utilize the airspace through enhanced operational procedures and applications.

A study to identify and analyze potential wireless aircraft-to-aircraft (A-A) and aircraft-to-ground (A-G) communications candidates for supporting the long term needs of the NAS has been initiated.

## NAS COMMUNICATIONS

NAS communications are anticipated to evolve from today's primarily voice communications to a future with much more highly capable voice and data communications that will enable a broad range of enhanced operations.

### *Today's Communications*

Today's NAS air-to-air and air-to-ground ATM-relevant communications are rather limited and consist primarily of VHF, HF, and SATCOM which support the traditional communications services, plus the use of L-band (978, 1030, and 1090 MHz) to support a number of surveillance and flight information services. Emerging or soon to emerge is the use of VHF data link (VDL) to support data communications between air traffic controllers and aircraft as well as the use of VHF Data Broadcast (VDB) to support GPS/Local Area Augmentation System (LAAS) Category I precision approaches.

### *Future NAS Comm. Candidates Overview*

Future concepts of operation for the long term national air transportation system within the study's 50 year time horizon include incorporating new types of aircraft (UAVs) as well as advanced operating procedures and applications that will drive the need for more and better A-A and A-G data communications.

Twelve alternative A-A and nineteen alternative A-G communications candidates have been identified. Figure 6 and Figure 7 list the air-to-air and air-to-ground communication candidates, respectively, that have been identified as part of the study. The A-A candidates include line-of-sight (LOS) candidates including VHF, UHF, L-band, C-band, S-band, X-band, optical, and hybrid RF/optical as well as one hop routing through future SATCOM systems that may include satellites in Geosynchronous (GEO) as well as in Low, Medium, or High Earth Orbits (LEO / MEO / HEO). The A-G candidates include LOS candidates from VHF to optical, as well as beyond line-of-sight (BLOS) candidates that include HF, SATCOM, and long range A-G communications enabled by A-A LOS communications hopping to one or more intermediate aircraft. Note that the

hopping alternatives are not at this time expected to be a primary mode of long-range A-G communications, but may provide a backup means of communicating with aircraft in oceanic, remote, and polar airspace when the primary means of communications (likely SATCOM) is not available. Having such a backup may allow in the future significant aircraft cost and weight savings by removing the need for HF communications equipment.

#	A-A Communications Candidates
1	VHF
2	UHF
3	L-Band
4	S-Band
5	C-Band
6	X-Band
7	Optical
8	Hybrid RF / Optical
9	LEO SATCOM (One hop through satellite)
10	GEO SATCOM (One hop through satellite)
11	MEO SATCOM (One hop through satellite)
12	GEO + HEO SATCOM (One hop thru satellite)

**Figure 6: Air-to-Air Candidates**

#	A-G Communications Candidates
1	HF
2	VHF
3	UHF
4	L-Band
5	S-Band
6	C-Band
7	Optical
8	Hybrid RF / Optical
9	Terrestrial K to W Band Network
10	DTV VHF/UHF Network
11	Cellular Network
12	LEO SATCOM Network
13	GEO SATCOM Network
14	MEO SATCOM Network
15	VHF A-A hopping for BLOS A-G comm
16	UHF A-A hopping for BLOS A-G comm
17	L-Band A-A hopping for BLOS A-G comm
18	X-Band
19	GEO + HEO SATCOM Network

**Figure 7: Air-to-Ground Candidates**

### *Initial Analyses of Communications Candidates*

As part of the study, initial analyses to characterize and evaluate the identified A-A and A-G candidates was completed. The analyses included:

- Quantifying the characteristics and attributes of each candidate including the communication bandwidth, latency, communications range, expected user data

rates, link spectral efficiency, capacity, availability, coverage, advantages and disadvantages, and technology readiness level (TRL);

- Identifying future NAS Air Traffic Management uses / applications and straw-man initial Required Communications Performance (RCP) to support them;
- Mapping the candidates to the ATM uses / applications based upon their ability to support the RCP;
- Identifying the infrastructure and architecture needed to implement each of the candidates; and
- Performing an initial security assessment of the candidates by identifying threats, vulnerabilities, and risk mitigation strategies relevant to the A-A and A-G data exchanges.

Additional analyses are planned including: 1) cost analyses, 2) use case analyses for a representative subset of possible future stressing applications including delegated separation and airborne self-separation, and 3) a prioritization of the candidates from most promising to least promising.

While the presentation of all the results from all of the assessments that have been completed is beyond the scope of this paper, a high level overview of the Required Communications Performance investigation for future airspace applications has been provided, followed by a summary of the interim study findings resulting from that assessment.

### ***RCP for Future Applications Investigation***

Required Communications Performance or RCP is a framework that has been developed by ICAO and other industry standards groups including RTCA and EUROCAE for characterizing the communications capability required to support performance-based Air Traffic Management (ATM) applications without reference to any specific communication technology.

RCP performance parameters have been defined by industry groups to include transaction expiration time (ET) for completing 99.9% of the transactions, transaction time (TT) for completing 95% of the transactions, continuity that the operational communication transaction can be completed within the ET, availability that the communication transaction can be initiated when needed, and integrity risk that the transaction is completed with an undetected error. It is expected that over time, the RCP definition will be revised and may eventually include the specification of additional measures of communications performance including those for information security.

While there has been considerable work within the industry on RCP, there is little consensus as to what RCP types will be required to enable a wide range future airspace applications. Aircraft applications that can be

conducted are dependent upon the performance of the communication, navigation, and surveillance systems in the airspace, as well as other elements (e.g., Air Traffic Control services, airspace density) to ensure system safety as authorized by the aviation authority.

Aligned with the expected operational paradigm changes expected to occur in NextGen airspace and beyond (with a 50 year study time horizon), anticipated future airspace applications both near term and far term have been identified for the purposes of this investigation. Applications identified have included a representative set for all phases of flight including airport surface, terminal area, domestic enroute, and remote / oceanic / polar.

For example, a representative set of anticipated future airport surface applications have been identified and evaluated ranging from routine airport surface applications (e.g., providing taxi and departure clearances) to supporting more advanced applications (e.g., simultaneous runway operations, near zero visibility airport surface movement taxi, ground based runway incursion alerting). Other types of applications were also identified and assessed to identify their RCP including aircraft access to System Wide Information Management (SWIM), Flight & Weather Information Services, and communications with Aeronautical Operational Control (AOC) centers.

Likewise, a representative set of anticipated future airport terminal area applications have been identified ranging from standard arrival / departure / approach applications in use today (e.g., Category I/II/III ILS approach operations) to supporting more advanced applications including Closely Spaced Parallel runway Operations (CSPO), Delegated Interval (DI), Delegated Separation (DS), and 4D Trajectory Based Operations (TBO). Additional futuristic terminal area applications were also considered including reduced airspace separations well below 3 NM, additional approach applications (including simultaneous runway operations and LAAS-based Category III precision approach and landing operations), and advanced arrival/departure operations. Similarly, a set of relatively easy and potential future stressing applications were also identified and investigated for the oceanic, remote, and polar airspaces.

To operationally enable the applications identified and envisioned for NextGen and beyond, it has been postulated by our study team that a limited number of RCP types as identified in Table 1 may be sufficient to begin to realize that vision. The rationale for the RCP values are based upon very preliminary initial evaluations of the communications transactions performance necessary to support the set of potential future airspace applications identified. The evaluations have leveraged information available in industry guidance documents including, for example, RTCA, EUROCAE, and ICAO. The required

communication performance values identified for future applications are very preliminary and need additional operational, performance, safety, and security analyses to confirm that they are appropriate to enable the various

intended applications. These RCP levels have been further allocated down to the communication system's Required Communication Transaction Performance (RCTP) as indicated in Table 1.

**Table 1: Straw-man RCP and RCTP**

RCP Type	Required Communications Performance (RCP)						Required Communications Transaction Performance (RCTP)					General Types of Applications Supported by this RCP Type
	99.9% Expiration Time [ET] (sec)	95% Transaction Time [TT] (sec)	Continuity (probability / ft. hr.)	Availability (probability / ft. hr.)	Integrity Risk (probability / ft. hr.)	99.9% Expiration Time [ET] (sec)	95% Transaction Time [TT] (sec)	Continuity (probability / ft. hr.)	Availability Two Parties (probability / ft. hr.)	Availability All Parties (probability / ft. hr.)	Integrity Risk (probability / ft. hr.)	
RCP 10	10	6	≥ 99 [Typically ≥ 99.9]	≥ 99.9 [Typically ≥ 99.998]	1.0E-5	4	2	≥ 99	≥ 99.3	≥ 99.9	1.0E-5	RCP 10 may be applied to controller intervention capability supporting ATM applications in surface, terminal area, and enroute domestic airspaces.
RCP 30	30	15	≥ 99 [Typically ≥ 99.9]	≥ 99.9 [Typically ≥ 99.99]	1.0E-5	8	4	≥ 99	≥ 99.3	≥ 99.9	1.0E-5	RCP 30 may be applied to routine ATM relevant communications supporting applications in busy terminal areas.
RCP 60	60	30	≥ 99 [Typically ≥ 99.9]	≥ 99.9 [Typically ≥ 99.99]	1.0E-5	20	10	≥ 99	≥ 99.3	≥ 99.9	1.0E-5	RCP 60 may be applied to routine ATM relevant communications supporting applications in surface, terminal area, and enroute domestic airspaces. In the future, RCP 60 (with appropriate surveillance) may be applied to enable significantly reduced aircraft separations (10 NM or less) in oceanic, remote, and polar airspace.
RCP 120	120	105	≥ 99 [Typically ≥ 99.9]	≥ 99.9 [Typically ≥ 99.99]	1.0E-5	75	60	≥ 99	≥ 99.3	≥ 99.9	1.0E-5	RCP 120 may be applied to advisory communications in domestic airspace, and for controller intervention capability supporting separation assurance in oceanic/remote airspaces with smaller separation environment.
RCP 240	240	210	≥ 99 [Typically ≥ 99.9]	≥ 99.9 [Typically ≥ 99.99]	1.0E-5	150	120	≥ 99	≥ 99.3	≥ 99.9	1.0E-5	RCP 240 may be a basis for controller intervention capability supporting separation assurance in oceanic/remote airspaces with greater than or equal 30 NM lateral or greater than 5 minutes longitudinal separation.
RCP 400	400	350	≥ 99 [Typically ≥ 99.9]	≥ 99.9	1.0E-5	310	260	≥ 99	≥ 99.3	≥ 99.9	1.0E-5	RCP 400 may be used for controller intervention capability supporting separation assurance in current environments where separations are greater than 50 NM lateral or greater than 10 minutes longitudinal.

### Study Findings

Initial investigations identifying potential future NAS ATM applications and developing initial Required Communications Performance (RCP) levels to support them has resulted in the following interim study findings:

- The future NAS will require significantly more A-A and A-G communications to support the envisioned NAS NextGen and beyond airspace applications.

- Current A-A and A-G NAS communications links are insufficient to meet the anticipated future needs of the NAS.
- Commercial broadband communication networks are envisioned to expand beyond what is offered today to further support NAS ATM-relevant communications (primarily A-G, but also A-A).



- Aviation communication / navigation / surveillance systems will evolve during the 50 year NAS study time horizon to meet the changing needs of the airspace and its applications. NAS communications can potentially reuse aviation spectrum that is decommissioned by other NAS services.
- Future NAS communications systems will need to address a variety of information security challenges including for example, integrity, authentication, non-repudiation, availability / continuity, data separation, and confidentiality. Over time, such performance measures may become part of RCP.
- No one single communications data link technology can meet all the expected future A-A and A-G communications requirements for the NAS. A combination of various communication technologies will be needed to address the diverse aeronautical communications requirements across all the operational flight domains.
- The emerging and the predicted future communication technologies are envisioned to be able to meet the NextGen and beyond NAS aircraft-to-aircraft and aircraft-to-ground communication needs.

#### 4. XCELAR

Agile Defense DBA XCELAR (XCELAR) is under contract to NASA to perform a study of future air-to-air and air-to-ground datalink technologies as part of NASA's Airspace Systems Program. The study focuses on identifying technologies and potential solutions to address datalink needs of the air transportation system fifty years into the future. XCELAR's approach is designed to incorporate both technical and business considerations, and to consider the needs of General Aviation and Unmanned Aerial Systems in addition to those of air carriers and other jet operators. The perspective of the aircraft operator is an integral element of the evaluation process.

The anticipated functions and requirements of the NAS of the future were defined using input from NASA, industry, academia, and the study team, and were summarized in the *Future NAS Scenarios Report*. These scenarios were then used to derive the associated information flow and data communication requirements. In parallel, initial analysis of candidate link technologies was initiated, starting projected capabilities, loading and improvements of currently available technologies through the study period.

The results of the analysis of current technologies fall into three categories: those that are unlikely to remain viable without major changes; those that are likely to be unneeded, and those that are expected still to be viable and relevant parts of the 2063 NAS solution set. The current

1090 MHz transponder transmission system, in particular, is expected to reach its capacity limit during the study term. Conversely, the associated current 1030 MHz interrogation function is likely to become unneeded, and offers a potential path for implementing an optimized upgrade path for the current 1090 MHz functions.

Analog voice communication via AM VHF is expected to become obsolete and be supplanted by various digital means. The current DME/TACAN system is also anticipated to become largely obsolete by 2063, presenting a potential source of L-Band aviation spectrum where new capabilities could be implemented gradually, sharing spectrum with the current functions on a non-conflicting basis during transition. By 2063 the evolution of onboard Inertial Reference Unit technology will enable the aircraft to continue navigation for significant periods of time without external references such as GPS; as a result, systems currently viewed as GPS backup navigation tools, such as DME/DME, TACAN and VOR Minimum operating Networks (MON) will no longer be needed.

Several current and emerging technologies are expected to continue to be valuable components of the future NAS through 2063 and beyond. These include the VDL Mode 2 VHF digital datalink, Ku/Ka-Band satellite systems, SATNAV, and AeroMACS. SATNAV capabilities will be enhanced by the deployment of emerging PseudoLite technology, augmenting satellite navigation signals with ground-based transmitters that are spectrally offset and have higher link margins. Iridium satellite communications, enhanced by Iridium-NEXT and the AIREON system of Space-Based ADS-B, will also provide valuable capabilities in the future NAS. SDARS will continue to be a viable data broadcast link for GA, as well as larger aircraft. ADS-B as a functional capability will be a fundamental component of NAS operations, but will transition from the current 1090 MHz transponder squitter link to a new, more spectrum- and cost-efficient link technology. The current UAT link for GA ADS-B will then be merged into the new link for a unified, all-user ADS-B system that does not require ground relay of ADS-B information from one system to the other to function.

Commercial communications such as cellular systems can also provide valuable and cost-effective communication services in the future NAS, with the caveat that current FAA and provider restrictions on ground-air-ground sue will require changes. There are ways of successfully addressing the concerns of high-altitude aircraft transmissions impacting ground-ground capacity, but companion regulatory and provider changes would be needed as well. Of potentially greater impact is the necessity for a viable business case to be made to the providers that the volume of airborne users would justify the required additional cost of developing, implementing, and operating the system. Additional antennas would

probably be needed, for example, to serve aircraft, in addition to allocations of portions of the available bandwidth. One interesting aspect of this is that application of cellular communications to low-altitude aircraft such as GA may require fewer technical and regulatory changes, offering the potential for a GA-only link. This could be viewed as offsetting to some degree the limitations of Ku/Ka-Band options to larger aircraft. However, the potential user base also will be smaller in terms of the provider business case – unless small UAS operations are included. The study team will be assessing these issues in more detail in year two of the program.

An important enabling technology has been identified, that harnesses the various future links into a seamless, delivery-focused function. This capability is based on a combination of current router functions, constant monitoring of each link and its status and availability trends, and intelligent analysis of pending information exchange needs, priorities, and delivery requirements. This “Delivery Manager” (DM) assures successful delivery of each information payload in accordance with its requirements for timeliness, security, receipt verification, and other criteria across the most viable link available and any time based on both technical and cost considerations. It is anticipated that regulatory approvals will be based in part on the ability of the DM to assure correct delivery across its set of available links, rather than the long-term performance of any single link. Among other things, this facilitates the inclusion of commercial links in the solution set, and becomes the enabler of “cloud communications” as a certifiable aviation tool.

Potential future links and functions at L-band were an area of particular focus, as L-band is well suited for use by GA and other small aircraft operators, in addition to air carriers. While Ku/Ka-Band satellite systems offer potentially significant bandwidth for larger aircraft, antenna considerations and equipment costs severely limit their applicability to GA and small-to-medium UAS use.

Software-Defined Radio technology will enable the availability of broadband, receivers that simultaneously receive and process the entire L-Band for all sizes of aircraft, enabling cost-efficient access to future capabilities including a new 1030 MHz ADS-B system, AeroMACS, ground-based navigation PseudoLites, and a new AeroWAN, or Aeronautical wireless Wide-Area Network. This L-Band SDR will also provide current functions including GPS and other SATNAV, SDARS, and reception of current DME, TACAN, and 1090 MHz ADS-B transmissions during transition. SATNAV functions will be improved, including autonomous reception, cross-check, and error correction of all available SATNAV systems (i.e., GPS, GLONASS, and Magellan), and of all signals from each systems, across a relatively wide spans (i.e., GPS L1, L2 and L5). Similar simultaneous reception and cross-

check of SATNAV and ground-based PseudoLite systems, as well as other RF sources of known locations, will further enhance accuracy, reliability, and jamming resistance of external navigation inputs to the aircraft.

The study team is currently analyzing the technical and cost aspects of a potential AeroWAN located in aviation L-Band spectrum currently used for DME and TACAN. This system would provide broadband ground-air communications via a network of ground stations employing a form of WiFi technology. This network would become the workhorse of the future system, being available for a wide range of information exchange on a hierarchical, prioritized basis. Potential functions include weather uplink/downlink (including downlink of onboard weather radar), AOC and AAC, airspace system status, digital voice, and even CPDLC and other air traffic communications. The underlying WiFi structure would also permit air-air information exchange through a ground-based routing function similar to wireless networks today. The AeroWAN system would serve air transport, business, and General Aviation as well as certain UAS communication functions.

Year 1 of the XCELAR Team study has established a clear basis for more detailed study in Year 2. The functions of the future NAS, and related communication requirements and potential link solutions, have been identified and categorized. The future of current technologies has been characterized, and required enhancements defined. Several key solution areas have been identified and defined for the next level of analysis and quantification. In year 2, more detailed technical analysis will enable identification of implementation costs and other issues, and business case analysis. Unmet needs will be identified, potential solutions defined and analyzed, and areas where further research is needed will be identified.

A number of viable and potentially beneficial solution paths have been identified, both within aviation spectrum and using commercial services. The future is expected to bring exciting innovations and growth to the industry as a whole, and the XCELAR Team is confident that they will be facilitated by viable and practical communication solutions, for all segments of the aviation community.

## 5. CONCLUSIONS

A NASA Research Announcement (NRA) study to investigate potential future aeronautical communication technologies that could serve aviation in the 2060 time frame was awarded in 2012. This NRA study is a one-year effort with an option that has been exercised for an additional year extension. The objective of this study is to investigate future air-ground communications technologies,

evaluate possible architectures, assess future communication needs, and identify challenges that will need to be addressed in the development and implementation of such potential systems. An important element of the study is to consider technological and Air Traffic Management advances planned for implementation by the NextGen and SESAR programs. NASA awarded the study to Rockwell Collins Corporation, Honeywell Corporation and Xcelar Corporation to independently conduct the study. This paper provides results obtained to date by each company.

Preliminary findings indicate that spectrum and technology certification will continue to pose a challenge, especially in areas where software is increasingly used to perform hardware functions. It is anticipated that although some spectrum will become available as a result of the decommissioning of technologies i.e. VOR, the demand for spectrum will increase and future technologies will need to provide the ability to maximize the use of finite spectrum resources. Advances in electronics and communications technology will enable the integration of services and applications and thus reducing the number of system deployed to the aircraft. Finally, the future aviation radio technology will depend on numerous factors including: air traffic management procedures, airline operations business models and the configuration of the airspace, which is anticipated to include Unmanned Aircraft Systems, hypersonic flights and manned aircraft.

#### ACKNOWLEDGMENT

The authors would like to acknowledge the funding and support of the NASA Aeronautics Research Mission Directorate's Airspace Systems Program Office at NASA Headquarters and NASA Ames Research Center; specifically: Dr. John A. Cavolowsky, Dr. Parimal H. Kopardekar, Mr. Rudolph A. Aquilina, and, Ms. Nazaret C. Galeon.

#### REFERENCES

- [1] Ponchak, Apaza, Wichgers, Haynes, and Roy, "A Study of Future Communications Concepts and Technologies for the National Airspace System – Part I", 32nd Digital Avionics Systems Conference, October 2013.

#### BIOGRAPHIES



**Denise S. Ponchak** is the Branch Chief of the Communications Networks and Architectures Branch at the National Aeronautics and Space Administration's (NASA) Glenn Research Center at Lewis Field in Cleveland, Ohio. The Branch is responsible for designing advanced networking concepts,

architectures, and technologies for aeronautics and space applications. Prior to becoming Branch Chief, Ms. Ponchak was an Aeronautical Communications Project Manager focusing on increasing the National Airspace System's telecommunications capability, and a communications research engineer supporting future satellite-based communications. She holds a Bachelor's of Electrical Engineering and a Master's of Science in Electrical Engineering from Cleveland State University in 1983 and 1988 respectively.



**Rafael Apaza** is a Communications Research Engineer at NASA Glenn Research Center. Prior to working for NASA, Rafael was the Communications Navigation and Surveillance (CNS) lead for the FAA Aviation Research and Development Office. In addition, Rafael supported the FAA's SWIM project, participating in both the SWIM Architecture Development and SWIM Transition projects. From 1999-2002 he was the FAA Great Lakes NAS Planning Program Manager for Michigan and Wisconsin. From 1987-1999, he worked as a systems engineer for FAA Airway Facilities, specializing in Communications and Surveillance. He holds a BSEE (1985), a MSEE (1995) from Wayne State University, and a MCIS (2001) from the University of Michigan.



**Joel Wichgers** is a Principal Systems Engineer working for Rockwell Collins in their Advanced Technology Center located in Cedar Rapids, Iowa. He has over 26 years of experience in aerospace engineering, at Rockwell Collins and McDonnell Douglas Aircraft Company (now Boeing Company). Joel has earned three college degrees including: a B.S. in Electrical Engineering from the Milwaukee School of Engineering in 1987; an M.S. in Electrical Engineering from Washington University in 1991; and, an M.S. in Electrical and Computer Engineering from Iowa State University in 1995. Joel has completed research and development in communications, navigation, and surveillance (CNS) systems; avionics flight decks; aircraft flight control and flight management systems; enhanced and synthetic vision systems; and air traffic management (ATM) technologies and systems in support of next generation (NextGen) airspace operations. Joel has 15 issued patents and has received numerous recognition awards during his career, including six citations from RTCA for his leadership and outstanding contributions to the development of aviation standards.



**Brian D. Haynes** - Mr. Haynes has served as a PI for NASA, DHS, DoD, and FAA in aviation research, development, policy-making, and technology assessment programs over the last three decades. Mr. Haynes's work has related to National Airspace System architecture /

operations, aircraft sensor systems, airport moving maps and runway incursion prevention, Electronic Flight Bag human factors, RF interference with aircraft navigation and communication systems, NGATS, and other areas requiring the melding of multi-disciplinary aviation expertise into innovative, relevant research results.

Mr. Haynes has been involved in aerospace technology and research for over 30 years. In addition to his experience with the above-mentioned programs, he has been an industry leader in avionics, weather, datalink, and missile defense technologies. As head of Flight Operations Technology at United Airlines, he led many related initiatives including NAS capacity enhancement, wake sensing technologies, fleet avionics equipage strategy, and business case development for flight operations technology programs.



**Mr. Aloke Roy** is a Senior Program Manager with Honeywell Advanced Technology organization; he currently manages data communication, information security and radio technology development programs supporting aerospace industries. Previously, Mr. Roy was Director of Programs at Flextronics Corporation

managing several major telecommunications OEM accounts. In this role, Mr. Roy was responsible for business development, outsourcing, and globalization of hardware design activities supporting large volume contract electronic manufacturing. His prior experiences include various positions at Bell Laboratories and ARINC Aviation Systems Division. Currently, he chairs ICAO ACP Working Group 'S' and RTCA Special Committee 223, which are developing the Aeronautical Mobile Airport Communication System requirements and operational performance standards. Mr. Roy holds an MBA degree from University of Maryland-College Park and an MSEE degree from Louisiana State University.



# A Study of Future Communications Concepts and Technologies for the National Aerospace System (The First Twelve Months)

Mr. Alope Roy  
Honeywell International, Inc.

Mr. Brian Haynes  
Agile Defense

Mr. Joel M. Wichgers  
Rockwell Collins

Ms. Denise Ponchak and Mr. Rafael Apaza  
NASA Glenn Research Center

# NRA Background

- NASA Research Announcement (NRA) “Research opportunities in Aeronautics”, NNH11ZEA001N, Released on August 26, 2011
- NNH11ZEA001N Amendment: C-2 Concepts and Technology Development Project (CTD1). Proposals due 4/3/12.
- Research is to support the 2011 NASA Strategic Plan Sub-Goal 4.1: Develop innovative solutions and advanced technologies, through a balanced research portfolio, to improve current and future air transportation.
- ARMD/ASP/CTD Subtopic 3: Technology Candidates for Air-to-Air and Air-to-Ground Data Exchange
- NASA anticipated the total funding of CTD1 Subtopic 3 to be in the range of \$250K/year for each award. The anticipated duration is 24 months from the date of the award.
- Three awards were made.

# CTD1 Subtopic 3: Technology Candidates for Air-to-Air and Air-to-Ground Data Exchange

Objective: Identify several long-term technology candidates that will allow air-to-air and air-to-ground data exchange. The specific goals are as follows:

1. Identify existing or emerging technology candidates (and their integration), including but not limited to ADS-B, suitable for air-to-air and air-to-ground communications over a NAS modernization horizon of 50 years.
2. Quantify the functional attributes and characteristics of each candidate, including communications range, bandwidth, latency, integrity, reliability, and security.
3. Map the technology candidates to specific air traffic management applications where they will be most beneficial and cost effective.
4. Identify the infrastructure and architecture needs of the potential technologies for air-to-air and air-to-ground exchange.
5. Identify rough magnitude cost estimates, or relative cost comparisons, and any technological characteristics such as bandwidth, and reliability.
6. Assessment how these technologies could be used for air traffic management applications including airborne separation and interval management.
7. Identify vulnerabilities and security issues and mitigation of any proposed concepts.

# NRA Awardees

- A Study of NAS Data Exchange Environment through 2060
  - Honeywell (Columbia, MD)
  - Aloke Roy, PI
- NASA Com50
  - Rockwell Collins (Cedar Rapids, IA)
  - Joel Wichgers, PI
- Technology Candidates for Air-to-Air and Air-to-Ground Data Exchange
  - Agile Defense LLC (Hopkins MN)
  - Daniel Johnson, PM
  - Brian Hayes, PI



# **A Study of NAS Data Exchange Environment through 2060**

**IEEE Aerospace Conference  
March 2, 2014**

**Honeywell Aerospace Advanced Technology**

**Aloke Roy  
Columbia, MD**

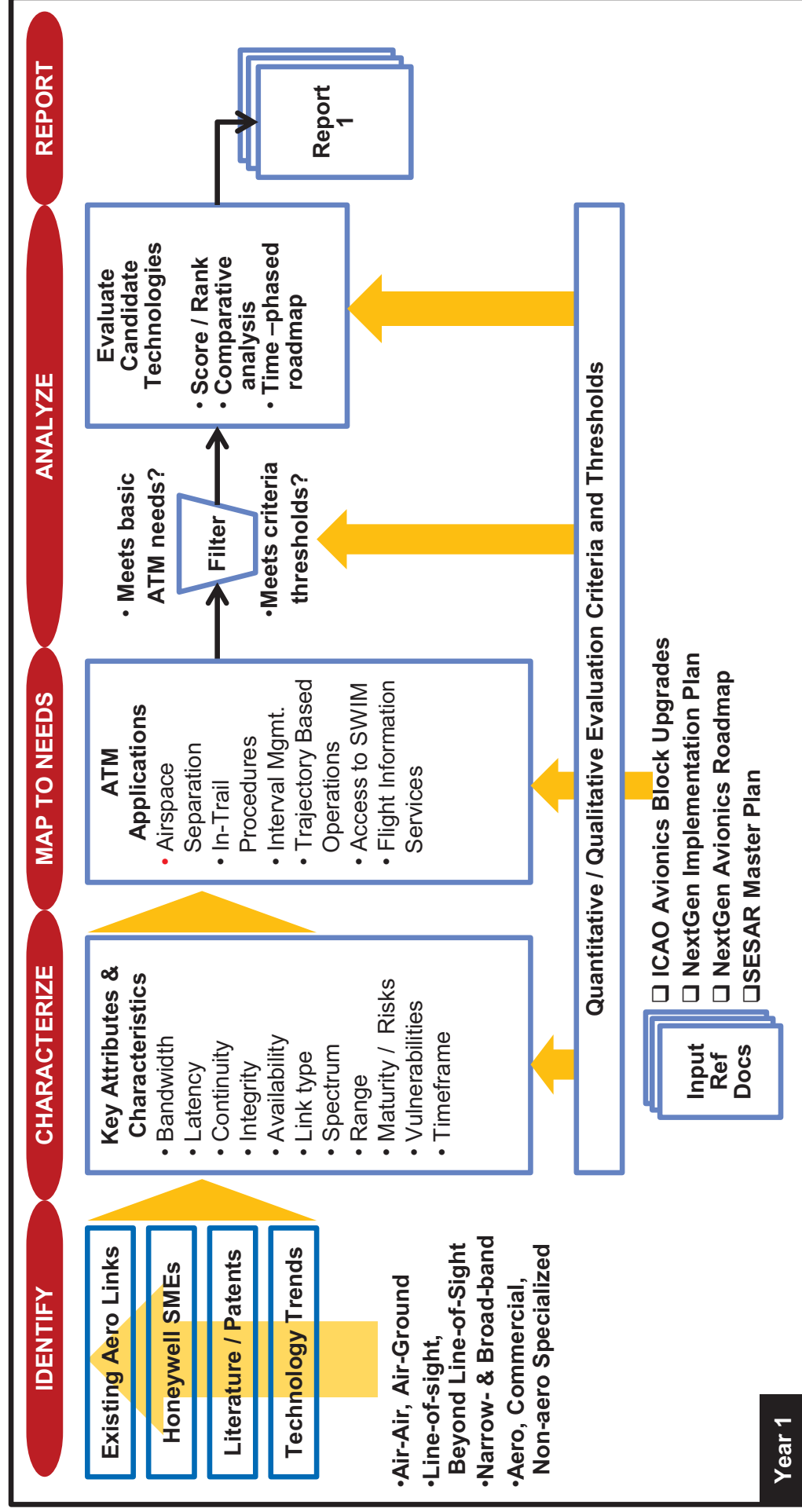
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**Tel: +1 (410) 964-7336**

**Honeywell**

# Technical Approach



# Technology Rankings from Task-1

## Air-to-Air Communications:

Rank	Airspace	APT	TMA	ENR	ORP
1		SO-VHF	SO-VHF	SO-VHF	SO-VHF
2		AeroMACS	L-DACS	L-DACS	Ku SATCOM
3		L-DACS	Cellular 4G/5G	Cellular 4G/5G	INMARSAT SBB
4		Cellular 4G/5G	Ku SATCOM	Ku SATCOM	
5			INMARSAT SBB	INMARSAT SBB	

## Air/Ground Communications for ATM:

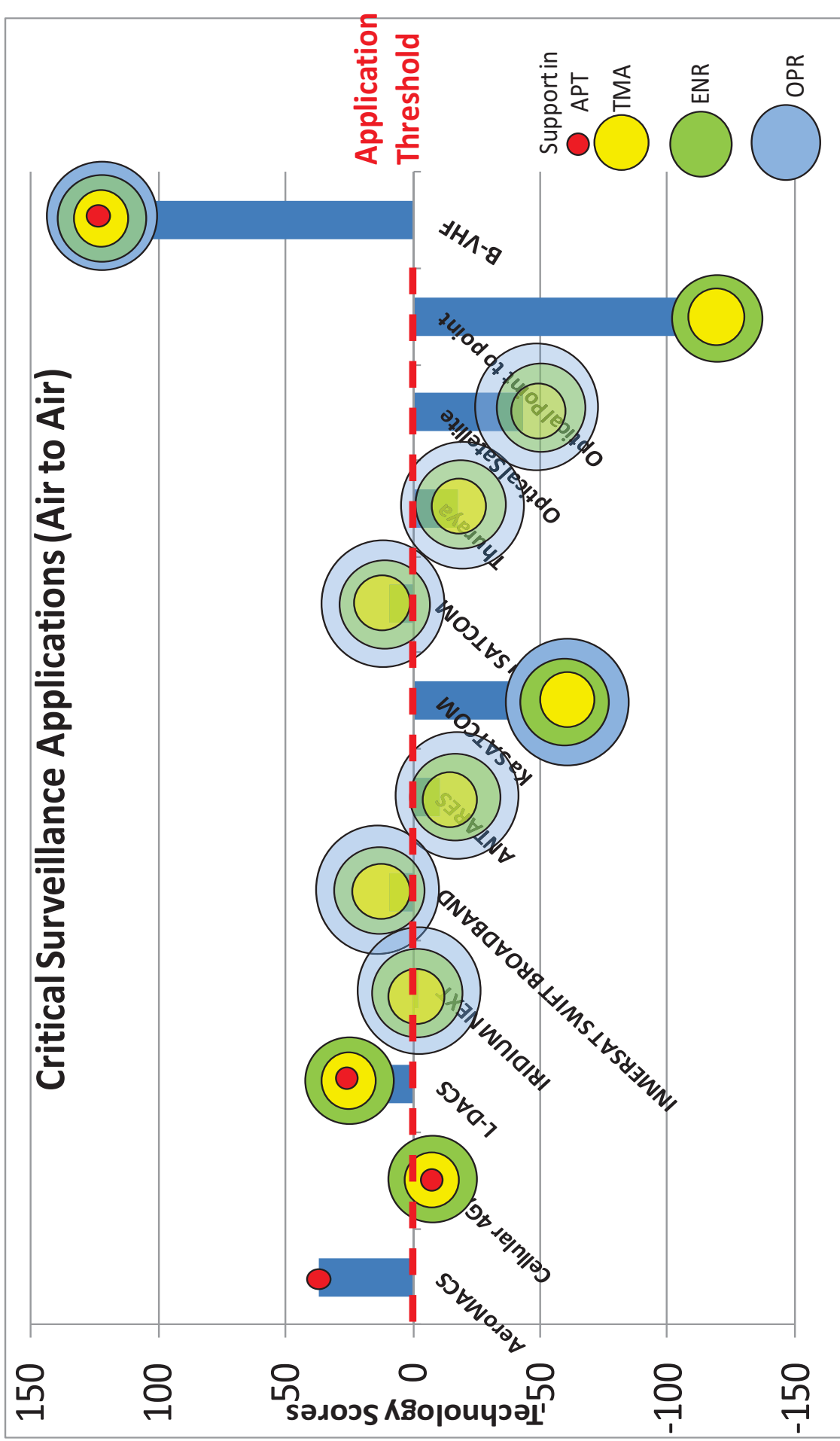
Rank	Airspace	APT	TMA	ENR	ORP
1		AeroMACS	SO-VHF	SO-VHF	Ku SATCOM
2		SO-VHF	L-DACS	L-DACS	INMARSAT SBB
3		L-DACS	Cellular 4G/5G	Cellular 4G/5G	
4		Cellular 4G/5G	Ku SATCOM	Ku SATCOM	
5		Ku SATCOM	INMARSAT SBB	INMARSAT SBB	

## High Bandwidth Future Communications:

Rank	Airspace	APT	TMA	ENR	ORP
1		Optical Point-to-Point	Optical Point-to-Point	Optical Point-to-Point	Optical Satellite
2		Optical Satellite	Optical Satellite	Optical Satellite	Ku Satellite
3		Cellular 4G/5G	Cellular 4G/5G	Cellular 4G/5G	Ka Satellite
4		Ku Satellite	Ku Satellite	Ku Satellite	
5		Ka Satellite	Ka Satellite	Ka Satellite	

# Technology Ranking for Air-to-Air Comm

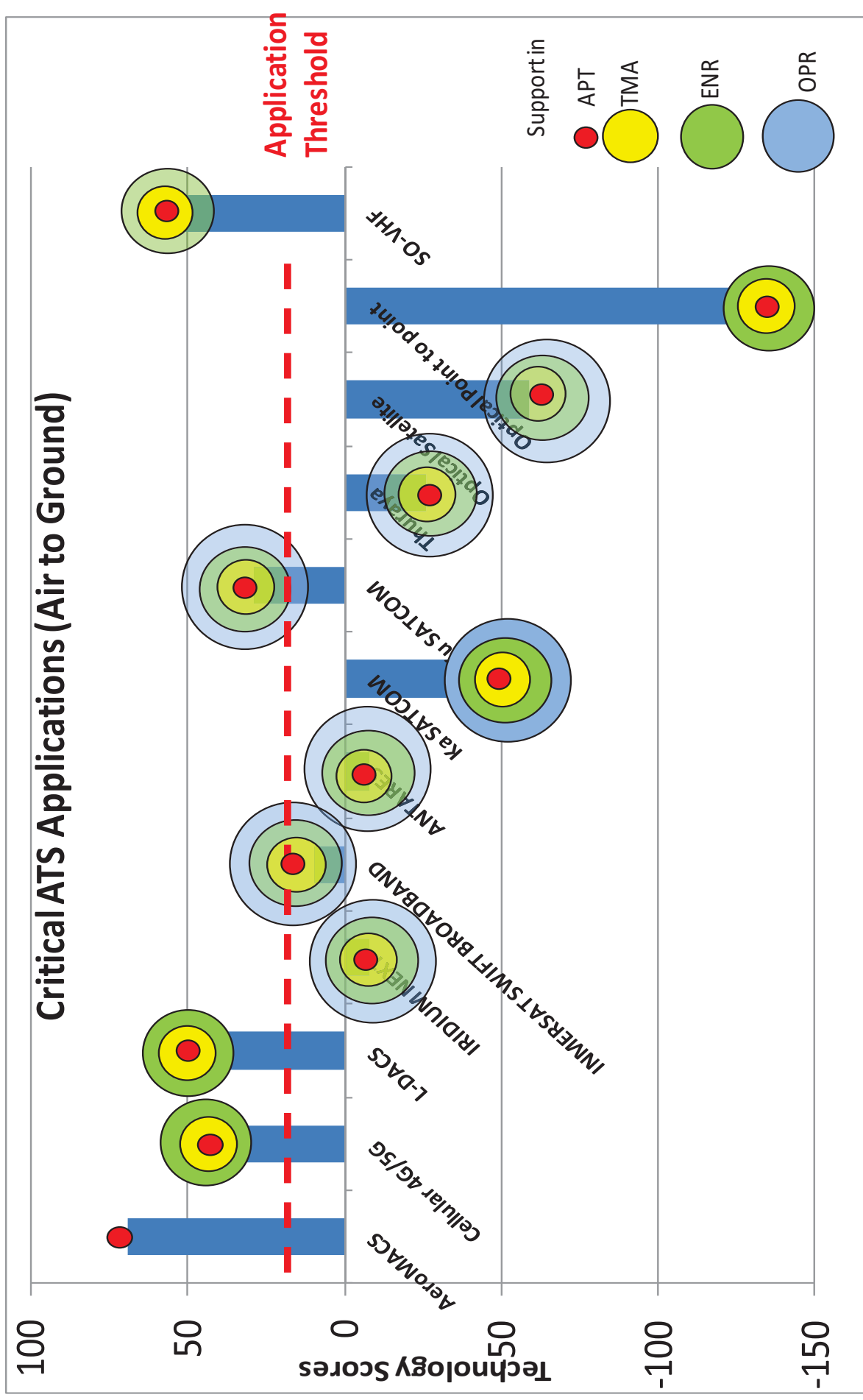
Honeywell





# Technology Ranking for Air-Ground Comm

Honeywell



- **Emerging technologies are well positioned to support NextGen communication needs**
- **Of the embryonic technologies, Free Space Optical technology is most promising**
- **Varied technology solutions will be needed to address diverse aeronautical requirements**
- **Hybrid solutions combining Free Space Optical with Satellite, L-band or wireless may support Beyond NextGen needs**
- **Algorithms demanding higher computing and signal processing capabilities will improve spectral efficiencies of future communication systems**

## Overview of NASA NRA research for the “Development of NextGen Concepts for Air-to-Air and Air-to-Ground Data Exchange”

*A forward looking study to identify long term candidates for meeting the air-to-air and air-to-ground communication needs of the NAS during a 50 year modernization time horizon.*

**Developed by: Joel M. Wichgers (PI)**

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e-mail: [jmwichge@rockwellcollins.com](mailto:jmwichge@rockwellcollins.com)

**Date:** March 2, 2014



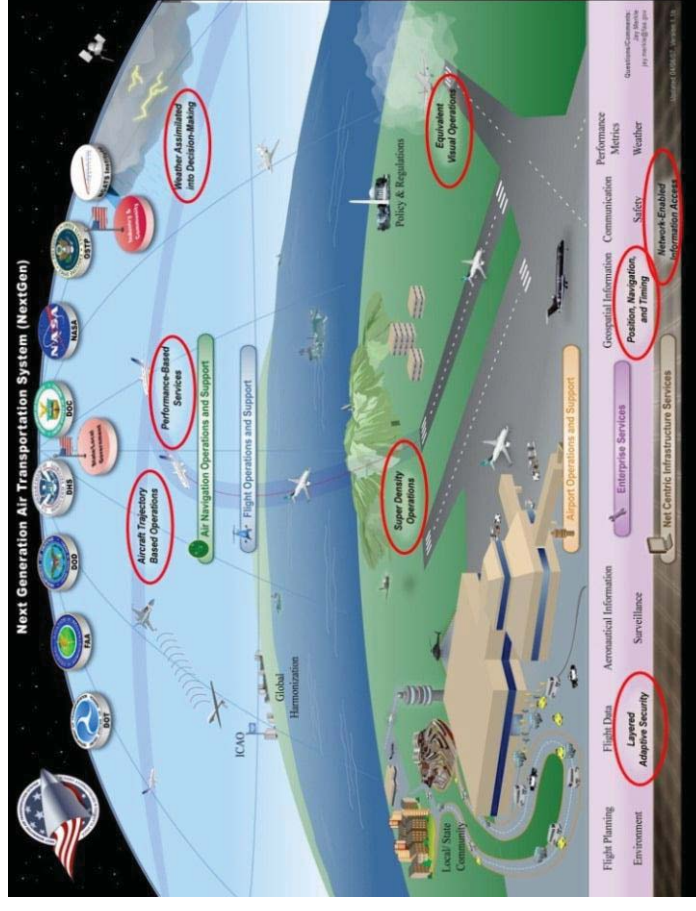
## The Next Generation Air Transportation System (NextGen) Vision for National Airspace

- **Today's National Airspace System (NAS)**

- Has served us well in meeting past operational and safety needs
  - Made effective and prudent use of air-routes, procedures, and traditional CNS systems to provide a level of capacity and safety that was sufficient for the demand
- However, without change, it will be unable to realize the capacity, efficiency, safety, security, and environmental improvements that are needed.

- **NextGen & Beyond Airspace**

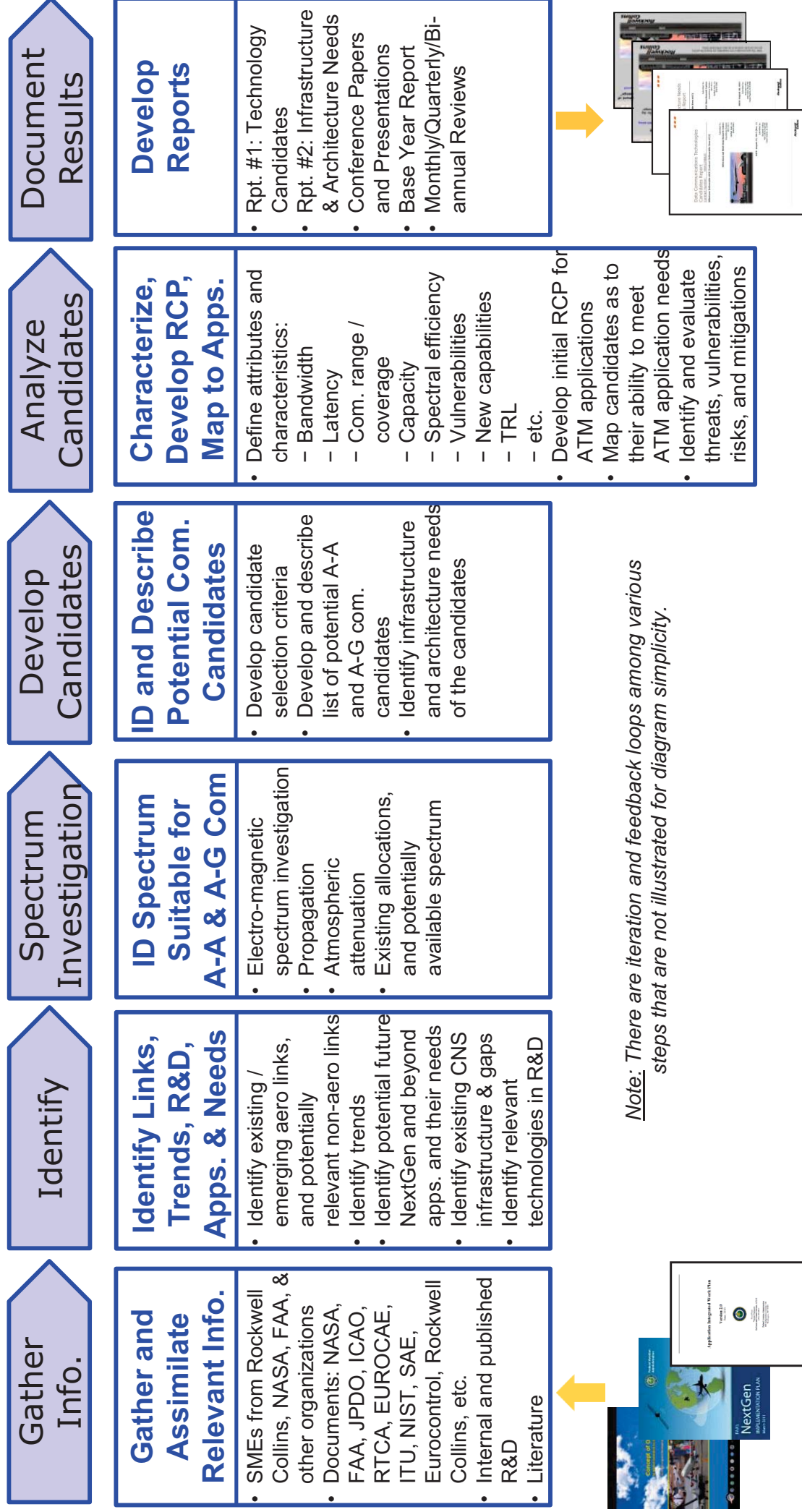
- Change way airspace is utilized/managed to achieve significant operational improvements
- Enable enhanced operating procedures
- Enabled with better Com/Nav/Surveillance systems, automation, decision support, human-machine interfaces, etc.
- Compatible with ICAO concepts and other international initiatives (e.g., SESAR)



Better Comm. is a key Enabler of NextGen & Beyond Airspace Vision



# Technical Approach for Base Year Study



## Base Year Technical Approach

# Identified 12 Air-to-Air and 19 Air-to-Ground Candidates

Current NAS Comm.		Future NAS Communications Candidates																																									
Air-to-Air (A-A)	<div>VHF: 122-123 MHz (CTAF)</div> <div>L-Band (Used for TCAS, ADS-B is Emerging on 1090MHz and 978 MHz)</div>	<div>VHF</div> <div>UHF</div> <div>L Band</div> <div>C and X Bands</div> <div>Optical &amp; Hybrid RF/Optical</div> <div>SATCOM</div> <div>(A-A One Hop Routed Through Satellite)</div>	<table><tr><th>A-A</th><th>Air-to-Air (A-A) Communications Candidates</th></tr><tr><td>1</td><td>VHF A-A</td></tr><tr><td>2</td><td>UHF A-A</td></tr><tr><td>3</td><td>L-Band A-A</td></tr><tr><td>4</td><td>S-Band A-A</td></tr><tr><td>5</td><td>C-Band A-A</td></tr><tr><td>6</td><td>X-Band A-A</td></tr><tr><td>7</td><td>Optical A-A</td></tr><tr><td>8</td><td>Hybrid RF/Optical A-A</td></tr><tr><td>9</td><td>LEO SATCOM A-A (One Hop through Satellite)</td></tr><tr><td>10</td><td>GEO SATCOM A-A (One Hop through Satellite)</td></tr><tr><td>11</td><td>MEO SATCOM A-A (One Hop through Satellite)</td></tr><tr><td>12</td><td>GEO + HEO SATCOM A-A (One Hop through Sat.)</td></tr></table>	A-A	Air-to-Air (A-A) Communications Candidates	1	VHF A-A	2	UHF A-A	3	L-Band A-A	4	S-Band A-A	5	C-Band A-A	6	X-Band A-A	7	Optical A-A	8	Hybrid RF/Optical A-A	9	LEO SATCOM A-A (One Hop through Satellite)	10	GEO SATCOM A-A (One Hop through Satellite)	11	MEO SATCOM A-A (One Hop through Satellite)	12	GEO + HEO SATCOM A-A (One Hop through Sat.)														
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Air-to-Ground (A-G)	<div>HF: ~3-30 MHz</div> <div>VHF: 118-137 MHz (VHF Data Broadcast for LAAS is just emerging in 112 – 118 MHz)</div> <div>L-Band (ATCRABS Transponder, FIS-B, ADS-B is Emerging)</div> <div>SATCOM</div>	<div>HF</div> <div>VHF: 108-137 MHz</div> <div>UHF</div> <div>L Band</div> <div>C and X Bands</div> <div>Optical &amp; Hybrid RF/Optical</div> <div>SATCOM</div> <div>Terrestrial K to W Band</div> <div>A-G Com. Via A-A Hopping</div>	<table><tr><th>A-G</th><th>Air-to-Ground (A-G) Communication Candidates</th></tr><tr><td>1</td><td>HF A-G</td></tr><tr><td>2</td><td>VHF A-G</td></tr><tr><td>3</td><td>UHF A-G</td></tr><tr><td>4</td><td>L-Band A-G</td></tr><tr><td>5</td><td>S-Band A-G</td></tr><tr><td>6</td><td>C-Band A-G</td></tr><tr><td>7</td><td>Optical A-G</td></tr><tr><td>8</td><td>Hybrid RF/Optical A-G</td></tr><tr><td>9</td><td>Terrestrial K to W Band Network (e.g., Ku Band QualComm+)</td></tr><tr><td>10</td><td>DTV VHF/UHF Network</td></tr><tr><td>11</td><td>Cellular Network (e.g., Aircell)</td></tr><tr><td>12</td><td>LEO SATCOM Network (e.g., Iridium Next+)</td></tr><tr><td>13</td><td>GEO SATCOM Network with global / regional / spot beams (e.g., Inmarsat Global Xpress+, Viasat I, Hughes NextGen, Broadcast Sat. TV+)</td></tr><tr><td>14</td><td>MEO SATCOM Network (e.g. GlobalStar+)</td></tr><tr><td>15</td><td>VHF A-A Hopping for long range A-G Com.</td></tr><tr><td>16</td><td>UHF A-A Hopping for long range A-G Com.</td></tr><tr><td>17</td><td>L-Band A-A Hopping for long range A-G Com.</td></tr><tr><td>18</td><td>X-Band A-G</td></tr><tr><td>19</td><td>GEO + HEO SATCOM Network</td></tr></table>	A-G	Air-to-Ground (A-G) Communication Candidates	1	HF A-G	2	VHF A-G	3	UHF A-G	4	L-Band A-G	5	S-Band A-G	6	C-Band A-G	7	Optical A-G	8	Hybrid RF/Optical A-G	9	Terrestrial K to W Band Network (e.g., Ku Band QualComm+)	10	DTV VHF/UHF Network	11	Cellular Network (e.g., Aircell)	12	LEO SATCOM Network (e.g., Iridium Next+)	13	GEO SATCOM Network with global / regional / spot beams (e.g., Inmarsat Global Xpress+, Viasat I, Hughes NextGen, Broadcast Sat. TV+)	14	MEO SATCOM Network (e.g. GlobalStar+)	15	VHF A-A Hopping for long range A-G Com.	16	UHF A-A Hopping for long range A-G Com.	17	L-Band A-A Hopping for long range A-G Com.	18	X-Band A-G	19	GEO + HEO SATCOM Network
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## Completed a Set of Analyses that Characterize and Begin to Evaluate Each of the A-A and A-G Candidates

- Quantified attributes, characteristics, strength/weaknesses of the candidates [e.g., the Actual Communication Performance (ACP)]
- Identified Future Air Traffic Management (ATM) applications & straw-man Required Communication Performance (RCP) needed to support them
  - The conference paper identifies a notional set of RCP types intended to support a broad range of envisioned NextGen and beyond ATM applications
- Mapped candidates to ATM uses/applications based upon their ability to support the RCP
- Identified infrastructure and architecture needed to implement each of the candidates
- Performed an initial Security Assessment of the candidates by identifying threats, vulnerabilities, and risk mitigation strategies relevant to the A-A and A-G NAS data exchanges

– Notes:

- Initial analyses have been completed. Before any candidate is seriously considered for NAS operations, further analysis, stakeholder vetting, cost benefits, etc. is needed.
- While there is insufficient time to discuss the details of each of the evaluations, a summary of the study findings from the evaluations is provided on the next 3 slides

## Summary of Interim Study Findings (Slide 1 of 2)

- Current NAS communications links are insufficient to meet future needs and more A-A and A-G data communications will be needed
- Current NAS Com. is inefficient by today's state of practice
  - Current state of the art for wireless communications achieves ~60% of Shannon's channel capacity limit. 60+% will likely become the state of the practice for wireless comm. during the modernization time horizon.
  - Wireless communications technologies are advancing in many areas that will lead to significant increases in the spectral efficiency
- Users of the spectrum (including aviation) will need to improve their spectral efficiency to enable the spectrum to meet future demands
  - Obtaining significantly more spectrum allocation to support NAS A-A and A-G communications will become increasingly challenging
- Commercial broadband will expand beyond what is offered today to further support NAS communications
- NAS data communications can potentially reuse aviation spectrum that is decommissioned / or not being used by other NAS services

## Summary of Interim Study Findings (Slide 2 of 2)

- 5 fundamental strategic approaches have been identified for addressing the long term NAS communication needs
  - 1) Reduce need for comm. BW
  - 2) More efficiently use existing comm. spectrum
  - 3) Leverage commercial comm. networks
  - 4) Identify / reuse / repurpose “aviation” spectrum to support comm.
  - 5) Identify & obtain new spectrum allocations for comm.
- Future NAS communications systems will need to address a variety of information security challenges
  - For example: authentication, non-repudiation, confidentiality, data separation, as well as integrity and availability / continuity.
  - Additional security-relevant measures of performance will likely become part of RCP
- No one single communications data link technology meets all the expected future A-A and A-G communications requirements. Need to implement multiple comm. technologies.
- Emerging and the predicted future comm technologies are expected to be able to meet future NAS communication needs.





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# Technology Candidates for Air-to-Air and Air-to-Ground Data Exchange

## *An Operator's Perspective*



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# Overall Approach



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- Perspective of the aircraft operator is an integral element of the evaluation process
- Define future NAS operations first, then derive communication requirements – “form follows function”
- Parallel research paths define future data exchange requirements & potential candidates
- Analysis structure based on phase-of-flight and vehicle/operator types
- Operator perspectives include:
  - Air transport
  - Air transport using reduced-crew configurations and unmanned vehicles
  - General Aviation and Business Aviation operators (including Very Light Jets)
  - Other types of UAV operations
- Working assumption:
  - Current-style regulatory process will not drive future solutions
  - Assume that approval processes will evolve along with solution technologies

# 50-Year Future – Calibration Points



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## **50 years ago**

## **30 years ago**

- 1963 - B727 first flight
- 1963 – Lear 23 & Falcon 20 First Flight
- World’s first geosynchronous satellite launched
- 1963 – First Laser Ring Gyro demonstrated
- SELCAL Entered Service
- 1983 – First cellular telephone received  
FCC approval
- 1983 – First PDA (Psion 1)
  - 1993 – Apple Newton
- 1983 – GPS available for civil use
- 1981 – First Laser Ring Gyro certified
- ACARS Entered service

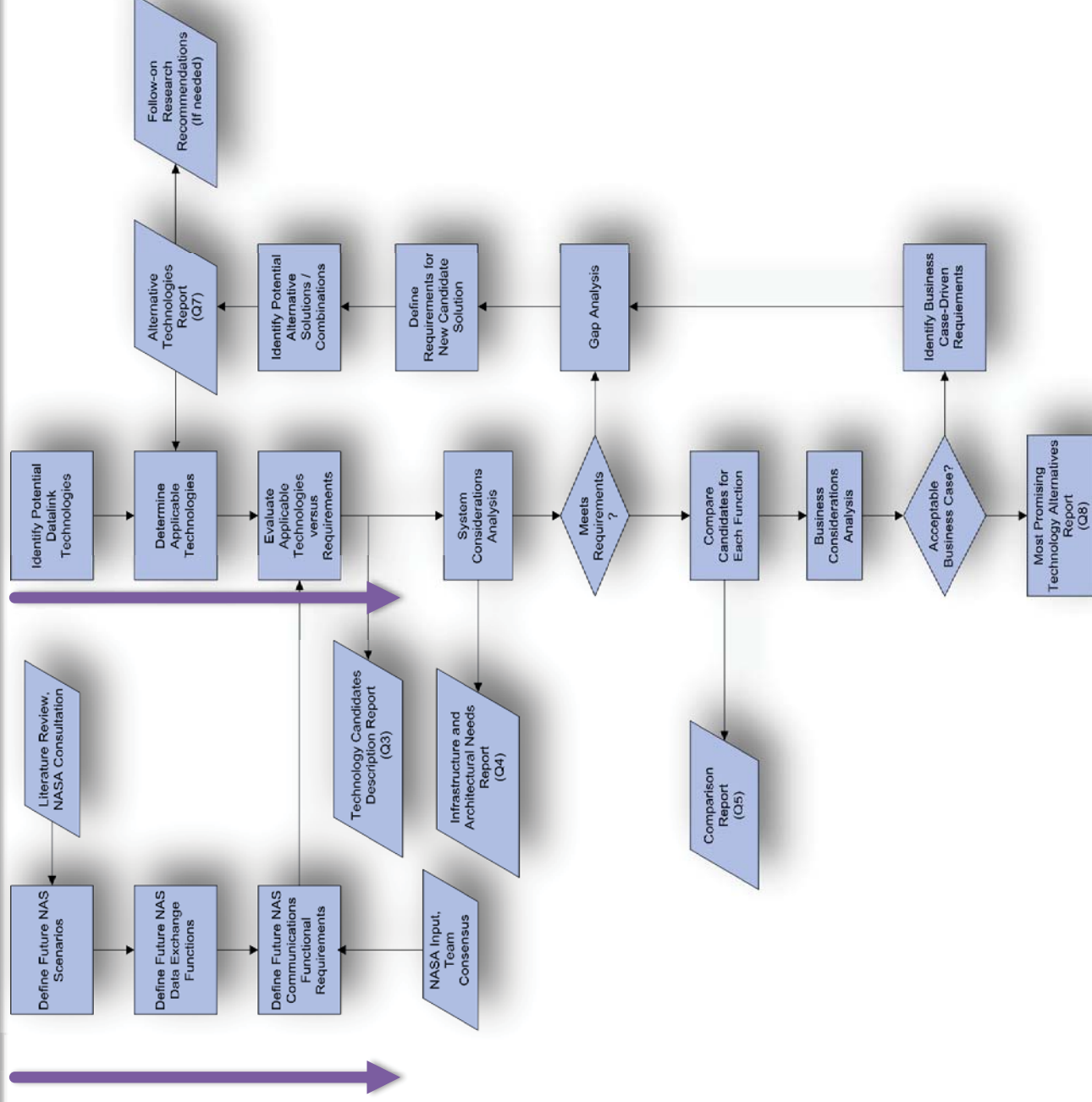
## **50 years from now**

- Primary users: Our children’s children and grandchildren
- Deep acceptance of “Connected Living”, Robotics
- Moore’s Law – type factors can be applied to: Bandwidth, link options, link cost

# Datalink Study Process



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# Future Solution Set:

- Will encompass a mix of aviation protected spectrum links and COTS delivery solutions
  - More efficient use of aviation spectrum for core functions like separation and guidance
    - Significantly better utilization of aviation spectrum
    - Major increases in available bandwidth and performance
    - Improved onboard navigation capabilities will allow more flexible communication choices
  - COTS delivery options for less-critical functions, and for fallback of core functions
  - All links & traffic managed by a “Delivery Manager”
    - Strategic Delivery Management
    - Access to multiple ISO layer information



# Future Solution Set:



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- ***Delivery Manager*** combines aviation-specific and commercial links into a seamless, robust, highly adaptable overall communication capability
- Majority of links identified are compatible with a wide range of aircraft sizes, performance, and operational paradigms
- Optimized use of aviation spectrum, especially L-Band
  - Major increases in bandwidth and performance are achievable within aviation protected spectrum over the study period
  - SDR technology enables both optimizations and reduced LRUs / cost
- **Aviation Specific Spectrum Solutions Include:**
  - VHF Datalink
  - Restructured ADS-B link systems
  - Space-based ADS-B
  - AeroMACS
  - New wireless Wide-Area Network (“AeroWAN”)
- **Commercial Links Include:**
  - Cellular Technologies
  - Iridium-Next (L-band and Ka-Band)
  - Satellite Digital Audio Radio Service (SDARS)
  - Ku / Ka band satellite



- **Delivery Manager** - Communications hub of the aircraft; It connects to:
  - Information systems on the aircraft that use or generate information
  - Communication links that the aircraft is capable of accessing
    - Aviation-specific links
    - Commercial or non-aviation specific links
    - Air – Ground, Air – Air, and Satcom
    - Air to Air relays to nearest Air-Ground Access Point
  - Assures delivery of communications at or above the required levels of:
    - Timeliness
    - Reliability
    - Integrity
    - Lowest practicable cost
  - Delivery decisions are made dynamically and without crew interaction
- **Broadband SDR**
  - Processes entire L-band from 960-1600 MHz simultaneously
  - Single LRU provides DME, TCAS, AeroWAN, Pseudolite, legacy 1090 and future 1030 ADS-B, UAT, GPS/SATNAV, SDARS, and ASRS-4
  - Provides “Delivery Manager” with link-layer communication management information
  - Same technology could provide all VHF SDR processing

# Enabling Technologies



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- **Re-Architected ADS-B Links**
  - Current 1090 / 1030 MHz system will not meet 50 year future needs
  - Very inefficient spectrum use in current 1090 / 1030 MHz system
  - Re-architected system provides:
    - Greatly increased bandwidth and functionality
    - SDR technology facilitates development, capability set, business case, and transition
    - Single system can serve both high and low altitude users
    - Straightforward transition path
- **AeroWAN**
  - Aeronautical Wide Area Network, or “AeroWAN” that can be used for a wide range of applications, data types, and message structures
  - Resides in L-Band spectrum allocated to aviation use
  - Simplify the current patchwork of niche technologies
  - Relatively small number of ground stations could serve a large number of aircraft and a wide range of information exchange functions
  - Another function of the multi-purpose SDR
  - Compatible with a wide range of aviation users

# Conclusions

- Preliminary findings indicate that spectrum and technology certification will continue to pose a challenge, especially in areas where software is increasingly used to perform hardware functions. It is anticipated that although some spectrum will become available as a result of the decommissioning of technologies i.e. VOR, the demand for spectrum will increase and future technologies will need to provide the ability to maximize the use of finite spectrum resources.
- Advances in electronics and communications technology will enable the integration of services and applications and thus reduce the number of systems deployed to the aircraft.
- Finally, the future aviation radio technology will depend on numerous factors including: air traffic management procedures, airline operations business models and the configuration of the airspace, which is anticipated to include Unmanned Aircraft Systems, hypersonic flights and manned aircraft.